Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences
Pacific Region
Canadian Science Advisory Secretariat
Science Advisory Report 2010/034

STATE OF THE PACIFIC OCEAN 2009

Context:

Pacific Canadian waters lie in a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions, and experience strong seasonality and considerable freshwater influence. Variability is closely coupled with events and conditions throughout the tropical and North Pacific Ocean, experiencing frequent El Niño and La Niña events particularly over the past decade. The region supports important resident and migratory populations of invertebrates, groundfish and pelagic fishes, marine mammals and seabirds.

Monitoring the physical and biological oceanographic conditions and fishery resources of this region is done semi-regularly by a number of government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, and Environment Canada. Contributors to this report are members of the Fisheries and Oceanography Working Group of the DFO Pacific Centre for Science Advice, with additional contributions from U.S. fisheries and climate scientists.

June 2010

Canada

SUMMARY

- Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by a number of government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. This eleventh report of an annual series updates the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems.

- One of the biggest stories for 2009 was the return of far fewer Sockeye salmon than expected. Accurately forecasting salmon returns is difficult as there are few observations of salmon between the time adults spawn in fresh water, and the time the next generation returns to British Columbia waters. Scientists base predictions of numbers of returning adult Sockeye salmon primarily on the empirical relationship between stock size (spawners, returns, or smolts depending on the stock) and consequent recruitment. For 2009, the forecast indicated there was a 90% probability the total run would be between 3.5 and 37.6 million Sockeye, yet the actual number was less than 2 million. Efforts to incorporate ocean indices to improve forecast performance were examined, and show promise for certain stocks; however, not Fraser River sockeye salmon at this time.

- Ocean temperatures off the west coast of Canada were cooler than normal at the beginning of 2009 but warmed through the summer and autumn. By early 2010 most regions along the American and Canadian west coast were above normal in temperature. The shift from cool to warm is likely in response to a change from La Niña to El Niño conditions in the tropical Pacific and a shift in ocean temperature patterns all across the North Pacific Ocean, called the Pacific Decadal Oscillation. The North Pacific Current has declined in strength from its peak flow in 2008. This eastward current splits into a northward flowing Alaska Current and southward flowing California Current, when it approaches the west coast of North America. The Alaska Current flow, in 2009, was the strongest in the eight years of continuous observations provided by the International Argo Program.

- Zooplankton are small animals drifting in the ocean's currents. The type of zooplankton available is thought to determine the growth and survival rates of juveniles of many endemic marine species. Species off the coast of Oregon and British Columbia, in the spring of 2009, were dominated by cool water groups that might be a better food source for endemic (native) marine life. These cool-water zooplankton dominated for the past three years of cooler ocean temperatures, although the dominant groups shifted to warm-water species in late summer 2009, along the outer continental shelf of southern Vancouver Island. Perhaps in response to the dominance of cool-water zooplankton in spring and early summer, many endemic species of seabirds on Triangle Island and in Pacific Rim Nature Preserve successfully raised chicks. Pink (smooth) shrimp numbers off the west coast of Vancouver Island increased in the May surveys of 2008 and 2009, from very low levels during 2004-2007. Such increases appear related to colder water when the shrimp were young, and to low abundances of Pacific hake. Many juvenile salmon from the Columbia River and west coast of Vancouver Island were larger in size or more numerous, or both, through spring and early summer of 2009, but their growth rates through summer and early autumn were low. Biomass of adult herring off Vancouver Island were low, attributed to several factors, including warmer ocean temperatures prior to 2007, when these adults were young and most sensitive to ocean temperatures and to the predators and prey associated with these conditions. Catches of Albacore tuna in Canadian waters, in 2009, were lower than average, attributed to these

cooler ocean temperatures. As noted above, several species along the west coast of Vancouver Island appear sensitive to interannual changes in ocean temperature; elsewhere this link is not as clear, and the timing of spring conditions or presence of predators might be more relevant. For example, herring in the Strait of Georgia are relatively high in number and year-to-year changes in their biomass does not follow changes in temperature.

- Humboldt squid appeared off the west coast in record high numbers in 2009. They were most abundant at several hundred metres depth, just seaward of the continental shelf among schools of Pacific hake, and were likely feeding on hake. Many of these squid were also observed closer to shore, and scores were found dead on west coast beaches. The biomass of Pacific hake off the Canadian coast seemed low, but assessment was difficult due to the many squid also observed among them.

- Several highlights are specific to the waters of central and northern British Columbia, which form the Pacific North Coast Integrated Management Area (PNCIMA). This region warmed later in the year than the Oregon, Washington and southern British Columbia coasts. Zooplankton species here also continued the dominance of cool-water groups. There are three stocks of herring in PNCIMA, and the biomass of adults of all three stocks is relatively low. Their biomass might increase if hake numbers remain low. The abundance of central and north coast Chinook salmon seems to be rebounding, from a low in 2008.

- Surface temperatures were generally above normal at most lighthouse stations in 2009 in the Strait of Georgia and Juan de Fuca Strait, but below the surface the waters remained relatively cool. Very high concentrations of phytoplankton were observed during the ship-based survey in April in the Strait of Georgia and in summer in Juan de Fuca Strait. Both were dominated by diatoms, as is normal for these regions. Satellite observations provide estimates of the concentration of phytoplankton at the ocean surface, when ship-based sampling is unavailable. These satellite observations reveal that when a plankton bloom appears very early in the Strait of Georgia, it is often associated with a bloom that is found in Malaspina Strait and also in Jervis Inlet. When viewed from space this bloom sometimes takes on the shape of a dragon, and it has acquired the name "Malaspina Dragon." These satellite measurements became available in 2001, and the Dragon appeared in 2005, 2008, and 2009.

- Finally, measurements of contaminants in cores from the bottom of the Strait of Georgia reveal past changes in the relative concentrations of contaminants in this region. Most contaminants that have been banned for many years, such as lead in gasoline and PCBs, are declining in concentration. In contrast, the concentration of flame retardant polybrominated diphenyl ethers (PBDEs) is increasing rapidly in sediment, despite its recent ban in Canada.

INTRODUCTION / BACKGROUND

This report is the eleventh in an annual series updating the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems. Canadian Pacific marine waters lie in a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions, and experience strong seasonality and considerable freshwater influence. Variability is closely coupled with events and conditions throughout the tropical and North Pacific Ocean, experiencing frequent El Niño and La Niña events particularly over the past decade. The region supports important resident and migratory populations of

invertebrates, groundfish and pelagic fishes, marine mammals and seabirds. Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by scientific staff in several government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, Environment Canada, and various other agencies.

This year's Fisheries Oceanography Working Group (FOWG) meeting at the Pacific Biological Station in Nanaimo, BC was preceded by a one day salmon workshop on 16 February 2010. This special workshop, chaired by Jim Irvine, examined ways to better incorporate oceanographic and climatic information into predictions of salmon survival and abundance; A total of 13 presentations were made, highlights of which were presented at the larger FOWG meeting. At the FOWG meeting on, 17-18 February, about 50 scientists met for presentations on the state of the ocean and its marine life in 2009 and early 2010. The FOWG meeting was chaired by Jim Irvine and Bill Crawford, both of Fisheries and Oceans Canada. Bill and Jim subsequently produced this summary report based on contributions by participants. More details are provided in Crawford, W.R. and J.R. Irvine. 2010. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053 available at http://www.pac.dfo-mpo.gc.ca/science/psarc-ceesp/osrs/index-eng.htm

ASSESSMENT HIGHLIGHTS

Low returns of Sockeye salmon to the Fraser River

Far fewer Sockeye salmon returned to the Fraser River in 2009 than expected. Scientists base predictions of numbers of returning adult Sockeye primarily on the relationship between stock size (spawners or juveniles depending on the stock) and associated recruitment. Accurately forecasting adult salmon returns is challenging, as there are many factors that affect salmon survival from their early egg and juvenile stages in freshwater, to their subsequent juvenile stage in the marine environment, and finally their adult stage in freshwater when they return to spawn.

In 2009, returns were below the forecasted 10% probability level (Figure 1). In generating the 2009 forecast, long-term average productivities had been assumed, which seemed reasonable given that marine indicators suggested that conditions for salmon going to sea in 2007 would be relatively good. Separate work is ongoing to examine the utility of other indicators, concentrating on those in the early marine environment of young Fraser Sockeye, in an attempt to help to reduce the uncertainties in forecast methodology.

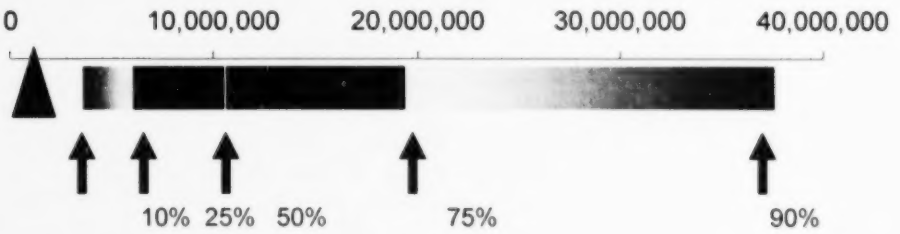


Figure 1. The 2009 total forecast probability distributions (indicated by blue arrows) for all Fraser Sockeye salmon stocks and 2009 preliminary returns (red triangle). Black horizontal bars represent the 25% to 75% probability distribution range with the 50% probability level indicated by the white vertical line and the blue (lighter) horizontal bars represent the 10% to 90% probability distribution range. (Contributed by Sue Grant of DFO and Catherine Michielsens of Pacific Salmon Commission)

Most Fraser River Sockeye enter the ocean in their second year of life and return as adults in their fourth year. For the 2009 adult return of Fraser River sockeye (2005 brood year, 2007 ocean entry), the productivity (recruits-per-effective female spawners) was amongst the lowest on record for most stocks. Sockeye Salmon originating from the Harrison River have a different life history strategy from most other Fraser River Sockeye stocks in that they enter the ocean in their first year of life and return as adults in their third and fourth year. Harrison Sockeye from the 2006 brood year that returned as three year old fish in 2009, exhibited below average productivity (preliminary estimate). Harrsion Sockeye from the 2005 brood year that returned in 2009 as four year old fish and in 2008 as three year old fish, exhibited the lowest productivity on record for this stock.

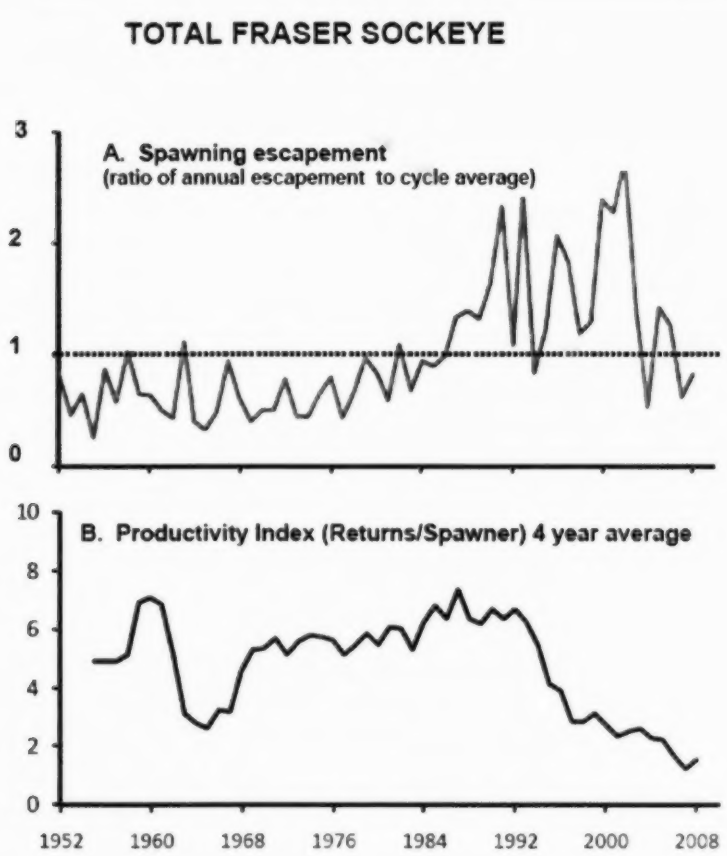


Figure 2. Time series of A. total spawning escapement (ratio of annual escapement to cycle average escapement) and B. productivity index (returns/spawner) smoothed using a running four year average. Note: In plot A, ratios above the blue dashed line are years when annual total escapements are greater than the cycle average and ratios below the blue dashed line are years when annual escapements are below the cycle average (from DFO, 2010. Pre-season run size forecasts for Fraser River Sockeye salmon in 2010. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/031).

Total productivity (returns/spawner) for most Fraser Sockeye stocks combined has been declining since the 1990's (Figure 2 B); this trend is dominated by Summer Run stocks that comprise the greatest proportion of Fraser Sockeye total production. Total escapement during this period was variable (Figure 1 A).

Based on stock-specific long-term trends in productivity, seven stocks have experienced systematic decreasing trends in productivity, starting in the 1960's-1970's (Early Stuart; Bowron; Fennell; Gates; Nadina; Seymour; Portage). Six populations including the four Summer Run stocks have experienced decreasing trends in productivity, starting in the 1980's-1990's (Pitt; Chilko; Late Stuart; Quesnel; Stellako; Birkenhead). Raft, Late Shuswap and Weaver have not exhibited long-term systematic trends in productivity and Harrison River Sockeye have exhibited increasing trends in productivity with the exception of the last few brood years.

Year of the Humboldt squid

In 2009, Humboldt squid were much more widespread and abundant in British Columbia waters than in previous years. They were recorded in both commercial and research catches from early July to October (Figure 3). They were densely aggregated; a three minute research tow yielded nearly 120 individuals and commercial bycatches were occasionally estimated in the tens of tons. In addition to catches and numerous sightings there were 10 significant stranding events reported throughout the exposed coast (Ucluelet to Massett) between August and October, as well as individuals washed onshore in Campbell River and Puget Sound in December.

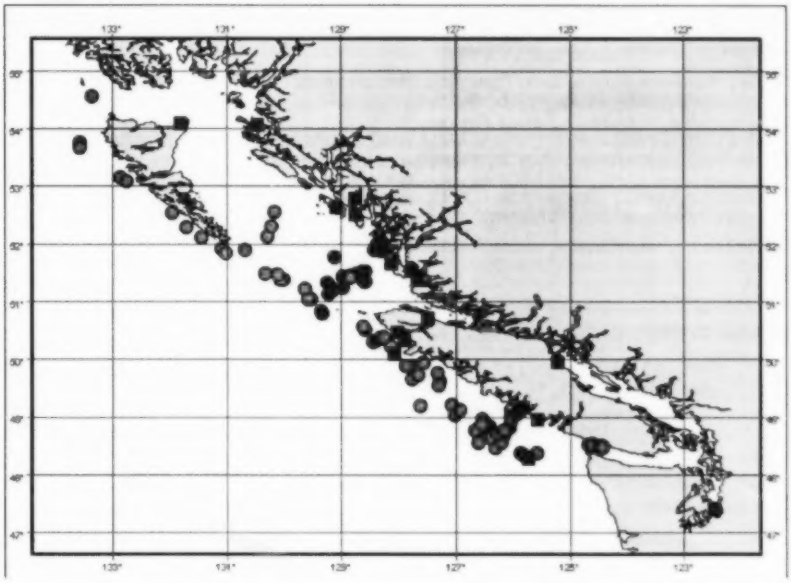
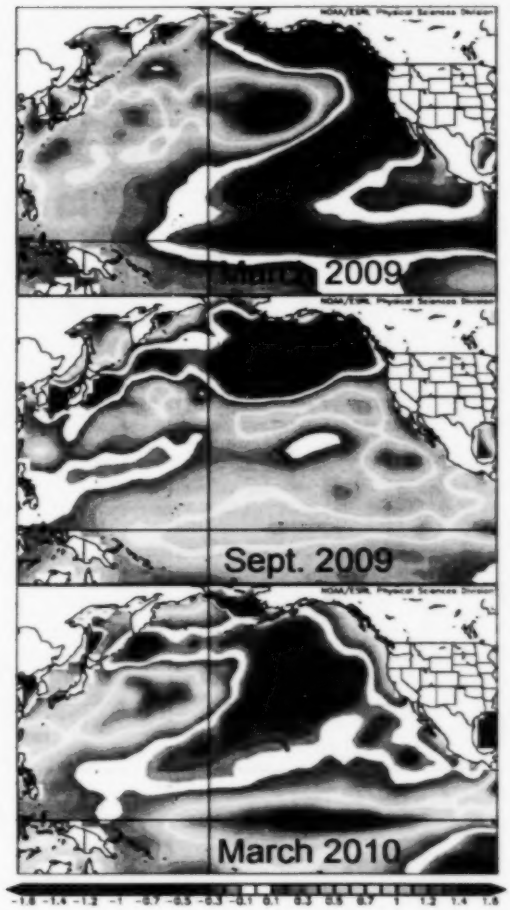


Figure 3. Records of Humboldt squid, Dosidicus gigas, *from British Columbia and Puget Sound in 2009 (blue squares are sightings, red squares are strandings, red circles are commercial bycatch and green circles are research catches). (Contributed by Graham Gillespie, DFO)*

Humboldt squid are seasonally-migrant, high-metabolism predators that can function as keystone predators in offshore and nearshore ecosystems. Most arrived in BC waters in summer 2009, and departed in autumn for southern US waters. They prey primarily on pelagic species such as hake, myctophids, anchovies, sardines, pelagic rockfish and other squid. Their diet could shift in northern waters depending on prey abundance, in particular depending upon the degree of overlap in time and space with salmon and herring.

Humboldt squid were observed frequently in the 2009 USA/Canada survey of Pacific hake along the west coast of Canada to central California. Both species tend to stay at depths of a few hundred metres, just seaward of the continental shelf during the day. There were so many squid among these hake that the normal acoustic images used to estimate hake abundance were highly irregular and not useable for the hake assessment itself. Humboldt squid are known to feed on Pacific hake. Their impact on hake numbers (and perhaps other marine species in summer) in future years could be extensive.

West coast waters are warming after several cool years



In last year's report the lead story described the unusually cold ocean waters west of British Columbia, Oregon and Washington all through 2008. These cold waters were still present in March 2009, as shown by the purple regions in the top panel of Figure 4 at left. In this plot the purple shading indicates more than a Celsius degree colder temperature than normal. In many areas it was much colder.

By August and September of 2009, the cold waters were farther offshore, with slightly warmer than normal temperature off Vancouver Island and all waters south to Mexico. These features are in the middle panel at left.

By March 2010, the waters near Canada and USA were warmer than normal, from shore out to several hundred kilometres, as shown by the yellow shading in the bottom panel at left. The cold waters were pushed farther south.

Figure 4. Ocean temperature anomalies in the Pacific Ocean. The map extends from North America to Asia, and from 65°N to 15°S. The Equator is marked by a horizontal black line in each panel; The vertical black line marks 180°W. The anomaly scale (at bottom) extends from minus 1.6°C in purple to plus 1.6°C in dark red. Images provided by NOAA Earth System Research Laboratory. (Contributed by Bill Crawford, DFO.)

This shift from cold to warm water west of Canada and the USA (including Alaska) accompanied a shift from La Niña to El Niño conditions on the Pacific Equator, which took place in 2009. In Figure 4 above one can see this shift in the change of colour along the Pacific Ocean Equator (horizontal black line in each panel), from purple in March 2009 to yellow-orange in September 2009, and finally to solid red in March 2010. This region on the Equator is "El Niño Central", where ocean temperatures respond most strongly to changes in the Southern Oscillation. The official El Niño and La Niña indices are defined by ocean temperature anomalies there. From mid-2009 to at least April 2010 these waters were sufficiently warm to trigger an official "El Niño" event, the strongest of this century.

In general, ocean temperatures along the Canadian and American west coast are relatively warm in El Niño winters and cool in La Niña winters. (The relative measure indicates warm and cool compared to normal temperatures for that month.) By this standard the shift to warm waters in 2010 was expected, and also predicted. (Air temperatures are normally warm too, and the warming in January to February 2010 impacted the Vancouver Olympic Games.)

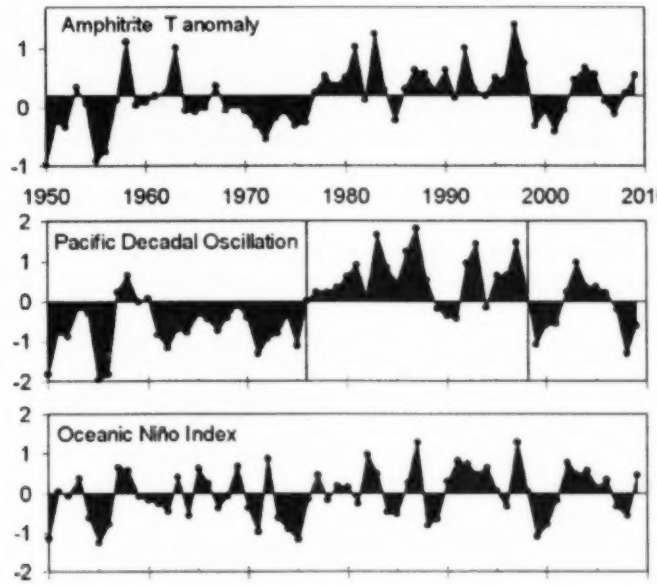


Figure 5. Anomalies of annual ocean temperature at Amphitrite Point, compared to time series of the Pacific Decadal Oscillation and the Oceanic Niño Index. (Contributed by Bill Crawford of DFO)

We can compare changes in local ocean temperatures with El Niño in Figure 5 at left. Amphitrite Point is a station on the southwest coast of Vancouver Island where ocean temperature has been measured daily since the 1930s.

The annual temperature anomaly here is compared in Figure 5 to annual values of the Pacific Decadal Oscillation (PDO) and the Oceanic Niño Index (ONI). PDO represents a pattern of temperature anomalies in the North Pacific Ocean, whereas ONI measures temperature anomalies in "El Niño Central" on the Equator of the Pacific Ocean. Generally an El Niño or La Niña triggers changes in atmospheric weather patterns in the North Pacific, which in turn can impact both PDO and Amphitrite temperatures. However, the PDO is also sensitive to slow changes in ocean currents in the western North Pacific Ocean. Until 1976, (Figure 5) it was mostly negative (a gray line marks this shift in 1976), but after 1976 and up to 1998 it was mostly positive (a second gray line marks 1998).

It has become common in the past ten years, since the discovery of the PDO by Nate Mantua, Steven Hare and colleagues, to attribute changes in ocean temperature and marine life along the west coast to PDO, based on the co-variability of PDO and local ocean temperatures until the 1990s. For example, one can see in Figure 5 that Amphitrite and PDO track each other well. However, since 1998 both the PDO and ONI have varied in phase, with common positive and negative intervals. As a result, ONI itself has become a useful indicator of local ocean temperatures, and because it tends to shift in phase before the PDO, it is a more useful predictor. We do not know if such co-variability of PDO and ONI will continue, but for now we can predict changes in local temperature and marine life reasonably well with the Oceanic Niño Index. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Small marine life in transition as west coast waters warm

Scientists of Fisheries and Oceans Canada estimate abundance and biomass for more than 50 zooplankton species, collected primarily during spring and late summer research cruises along the west coast of Vancouver Island and other locations. Zooplankton are small, often microscopic animals that drift in the ocean's currents. In the 30 years of these measurements, an alternating cold-warm pattern of species has emerged, with different species of zooplankton dominating in cold ocean years than in warm years. They are a sentinel of shifts in marine life, since they are usually the first species observed to respond to changes in ocean temperature. It appears that cold-water zooplankton species provide a richer source of food for predators than similar warm-water species.

In 2009, there was an almost complete shift in zooplankton species on the outer continental shelf of the west coast of Vancouver Island between late May and early September. The spring community was very strongly dominated by cool water crustaceans such as large copepods and euphausiids. The late summer and autumn communities were dominated by two warmer water non-crustacean taxa: the pteropod *Clio pyramidata*, and the doliolid *Dolioletta gegenbauri*. Southern copepods also increased from May to September, despite the fact that their usual annual maximum is during winter, when southerly winds drive peak poleward transport from southern source regions. *Clio* and *Dolioletta* are both individually large (circa 1 cm body length), but are probably too large and also too gelatinous and lipid-poor to be optimal prey for summer predators such as juvenile salmon, herring, and planktivorous seabirds.

Over the past 30-50 years, both *Clio* and *Dolioletta* were historically occasional biomass dominants off southern California. They were observed very rarely and intermittently off British Columbia. However, this latitudinal gradient of occurrence and dominance has changed dramatically this century. Figure 6 shows time series of annual anomalies of *Clio* and *Dolioletta* over the southern Vancouver Island continental shelf break and slope. Both species were either absent, or present only at very low abundance/biomass prior to 2000. Since the turn of the century, doliolids have had strong positive anomalies in most years. Generally, the abundance of copepods decreases as the abundance of *Dolioletta* increases in a given area. *Clio* is now occasionally extremely abundant. All 3 years with large positive anomalies of *Clio* have been during the past decade.

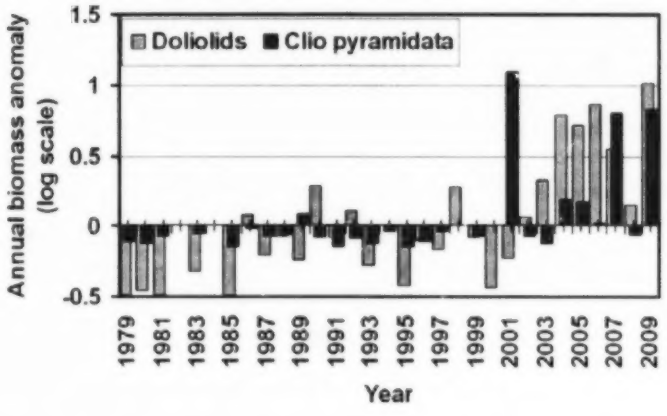


Fig. 6. Anomaly time series for large gelatinous herbivorous zooplankton off southern Vancouver Island. Graphed are doliolids (mostly Dolioletta gegenbauri*) and warm water thecosomatous pteropods (*Clio pyramidata*). Both are endemic to the mid-latitude Pacific south of the subtropic-subarctic transition zone, but occasionally invade the eastern subarctic Pacific. The frequency and intensity of invasion has increased dramatically since about 2000. (Contributed by David Mackas of DFO.)*

Bill Peterson of the NOAA Northwest Fisheries Sciences Center samples the ocean every two weeks off Newport Oregon, providing the most highly resolved time series of fast changes in zooplankton. He has observed how Pacific-wide changes in weather lead to shifts in ocean temperature near Newport, and also to changes in zooplankton. As a measure of the zooplankton community, he uses the copepod species richness, which is the number of copepod species observed in biweekly plankton samples. In general, warm waters have more species and this holds true for his Oregon time series.

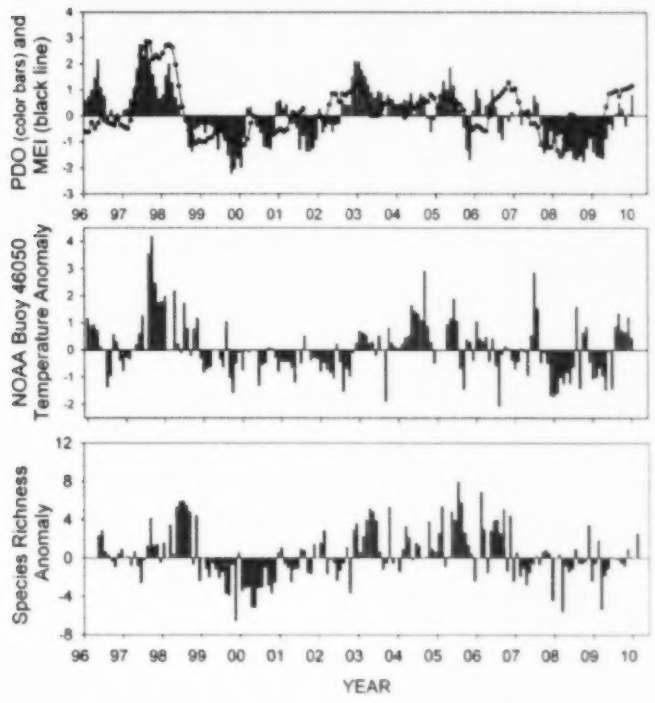

PDO (color bars) and MEI (black line)
NOAA Buoy 46050 Temperature Anomaly
Species Richness Anomaly
96 97 98 99 00 01 02 03 04 05 06 07 08 09 10
YEAR

Figure 7. Upper Panel. Time series of the Pacific Decadal Oscillation (PDO) and Multivariate ENSO Index (MEI) from 1996-2010. Middle Panel. Time series of monthly average sea surface temperature anomalies measured at the NOAA Buoy 46050 located 17 miles off Newport Oregon. Anomaly is calculated from the base period of 1991-2008. Lower Panel. Time series of the anomaly of monthly averaged species richness of copepods collected at a baseline station located 9 km off Newport. Species richness is the number of copepod species in a given zooplankton sample. Note that a persistent change in the sign of MEI is usually followed by change in sign of the PDO; note also that SST and copepod species richness follow MEI and PDO with a few months time. (Contributed by Bill Peterson of NOAA/Northwest Fisheries Science Center)

Bill Peterson applies the MEI, which is a time series of El Niño and La Niña closely related to the Oceanic Niño Index shown previously. One can see in Figure 7 that MEI, PDO and copepod species richness generally follow similar patterns from month to month. Species richness is another indicator of seasonal and interannual variations in ocean conditions. (Species richness is simply the number of copepod species observed in biweekly plankton samples.) Monthly average values for copepod species richness continue to track quite closely with the PDO and SST (Figure 7) such that when the PDO is negative, the copepod community is dominated by only a few cold–water, subarctic species. Conversely, when the PDO is positive, SST on the Oregon shelf is warm, and the copepod community is dominated by a greater number of warm–water, subtropical species. During 2009, there was moderately low biodiversity, but certainly no indication of an influx of an anomalously high number of subtropical species. This suggests that the warming observed in 2009 was localized, and not due to any northward transport of subtropical waters during summer or autumn of 2009, as a result of the El Niño event. Northern copepod biomass anomalies, for the year 2009, were also fairly high, 0.45, similar to values seen in 2007 (0.50), but less than values in 2008 (0.75).

By early 2010, Oregon coastal waters were above normal temperature, likely due to changes in wind patterns associated with El Niño.

Cool winter and spring is good news for many endemic species off the west coast of Vancouver Island

Relatively cool ocean waters were observed off Vancouver Island all through winter and spring of 2009. These relatively cool waters arrived in 2007 and persisted until waters warmed in summer 2009.

The cool ocean temperatures during the first half of 2009 were good news for many endemic (i.e. native) marine species. Often it is the availability of suitable prey that determines how a species responds to changes in temperature. Since cool water zooplankton are generally more

energy rich than warm water zooplankton, temperature related shifts in zooplankton species composition can influence the survival and growth of animals that consume zooplankton. Another factor is predator abundance, which can also be linked to ocean temperature.

A second measure of a cool-warm shift is the timing of spring transition off Vancouver Island. This transition marks the end of storm winds from the south and the onset of prevailing winds from the north. Since northerly winds are generally cool and also upwell cool waters along the coast, an early spring transition indicates cool ocean waters in spring. Scientists have tracked the timing of this transition for many years, monitoring the data from weather buoys and current meter moorings off Vancouver Island. Both data sets reveal earlier spring transition in 2009.

It appears an early spring transition is linked to years of good seabird breeding success. For example, when April ocean temperatures are cool and the spring transition is early, more juvenile auklets on Triangle Island survive to fly away from the nest. This island, off northern Vancouver Island, has the greatest concentration of seabirds in BC. Cool temperatures and northerly winds are indicators of the availability of good prey in nearby waters all through spring. Cassin's auklets on Triangle Island bred more successfully in 2007-2009, as expected for cool springs with early spring transition. In the Pacific Rim Marine Park Reserve off the west coast of Vancouver Island (WCVI), scientists note that most species of seabirds (except for the common murre) responded positively to the cooler local oceanic conditions observed in 2007 and 2008.

Recent surveys found the biomass of Pink (smooth) shrimp off WCVI, increased in 2008 and again in 2009, from very low levels during 2004-2007. Such increases appear related to colder water in previous years when the shrimp were young (this species has a 2-yr time lag from hatch to recruitment at age-2) and to low abundances of Pacific hake (a potential shrimp predator) in May surveys in 2008 and 2009.

Juvenile salmon usually survive their first year better along the outer Vancouver Island coast when spring and summer are cool. It is not ocean temperature itself that controls survival but, as noted above, it is likely the impact of temperature on their prey and/or predators.

Juvenile salmon along the outer Vancouver Island coast generally survived very well in the cool years of 2007 and 2008, and apparently in 2009 until waters warmed in summer. Catches of juvenile Chinook salmon (from the Columbia River) off the Washington and Oregon coast in June 2009 were the 4th highest in 12 years of sampling, attributed by American scientists to cool ocean waters. In Canadian waters, catch rates of juvenile Chum, Sockeye and Chinook salmon off Vancouver Island were highest ever in 2008. These are a mixture of Columbia and WCVI stocks.

Warmer water during the summer of 2009 may have negatively affected some juvenile Coho salmon. Their numbers in the spring 2009 survey were the highest ever, as noted in the left panel (final data point) of Figure 8 below. However, their growth rate between May and October 2009 was one of the lowest since observations began in 1998, coinciding with the onset of warmer local waters. We cannot determine conclusively why the growth rate plummeted, but their poor growth coincides in time with the shift of zooplankton species in these waters between May-June and August-September 2009, from cool-water species in May-June to warm-water species in August-September. (Details on this shift were described earlier.) However, zooplankton species shift was strongest on the outer continental shelf and juvenile Coho tend to stay closer to shore.

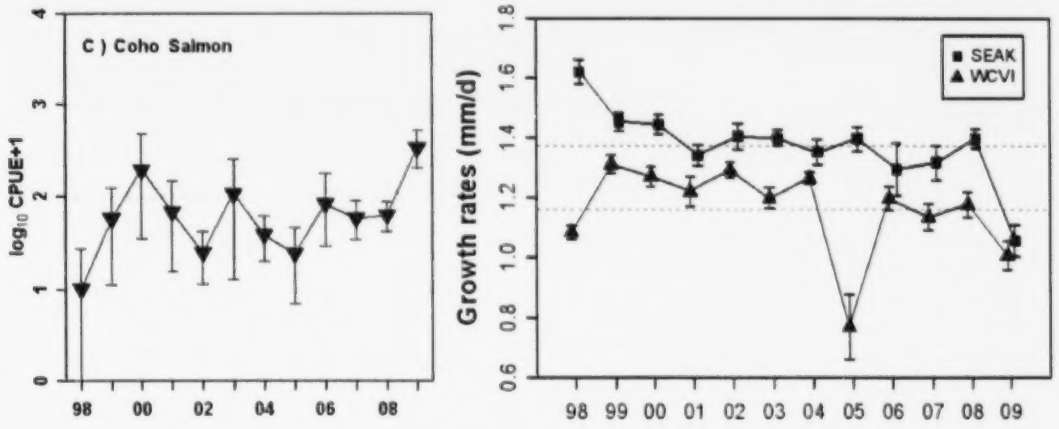
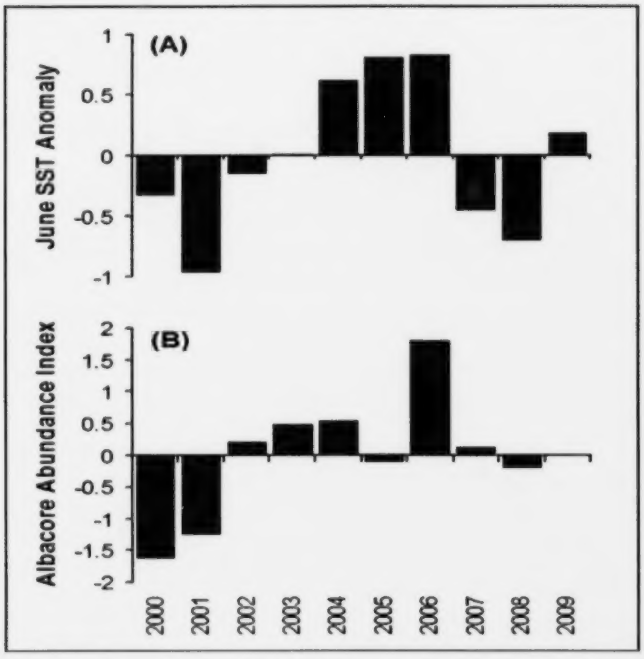


Figure 8. (left). Catch-per-unit-effort (CPUE) of Coho salmon off the west coast of Vancouver Island in June-July 1998-2009. Average CPUE and 95% confidence intervals were obtained by bootstrapping. (right) Growth rates (May-October) of juvenile Coho salmon off the west coast of Vancouver Island (red triangles, WCVI) and Southeast Alaska (blue squares, SEAK). The blue and red dotted lines represent the 1998-2009 average values for Southeast Alaska and the west coast of Vancouver Island, respectively. The error bars are 2 times the standard error. (Contributed by Marc Trudel of DFO.)

It is important to realize that good survivals do not necessarily mean good returns. Coho salmon that will return in 2010 are the progeny of smolts that went to sea in the warm spring of 2006, many of which experienced low marine survivals, producing low spawning escapements in 2007. Even with relatively high survivals, returns in 2010 are expected to be modest because of the low spawner numbers in 2007.

Abundance of the WCVI herring stock in 2009 was similar to low levels observed since 2006 and remained well below the fishery threshold. Herring take several years to reach a size suitable for fisheries (denoted as recruitment), so their availability to fisheries is largely determined by ocean factors in the years prior to recruitment. Research has shown that recruitment of WCVI herring tends to be negatively correlated with increasing temperatures, probably reflecting: 1) poor feeding conditions for young herring during their first growing season; and 2) increased mortality from predation in warm years. Studies investigating predation rates indicate that the negative correlation between herring recruitment and hake biomass could be caused by predation or competition for food. Ocean conditions were warmer in 2002-2005, impacting herring survival, resulting in reduced biomass and recruitment. However, cooler conditions, since 2006, and declining hake abundance, should improve herring recruitment in the future.

Pacific sardine provide another example of a delayed response to temperature. Pacific sardine is a migratory species, moving annually between spawning grounds in southern California to the rich feeding areas off the west coast of Vancouver Island. The sardine fishery in Canadian waters collapsed in 1947. Sardines reappeared off the west coast of Vancouver Island in 1992. From 1992 to 1996, their distribution was limited to the south-western portion of Vancouver Island. In the very warm summer of 1997, their distribution expanded northward, and by 1998, sardines extended into central and northern BC waters. In 2003 and 2004, the distribution of sardines in BC was limited to the inlets of Vancouver Island and offshore areas in the south, following the general cooling of BC waters from 1999-2002. Warm conditions in 2002-2006 and a very strong 2003 year-class resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound.



Albacore tuna appear close to Canada's west coast when waters are warm. June sea surface temperature (SST) anomalies at Amphitrite Point are used as a predictor of the availability of "tuna waters". The two graphs at left show this link between tuna catch and ocean temperature. Unlike other species, it is the migratory juveniles and adults that respond to ocean temperature.

Figure 9. June sea surface temperature (SST) anomalies at Amphitrite Point on the SW coast of Vancouver Island (A) and annual abundance index values (standardized albacore catch rate anomalies) in BC waters (B). Zero in both figures represents average conditions for the 1971-2000 (SST) and 2000-2008 (catch rates) periods. (Contributed by John Holmes of DFO.)

Marine life outside the WCVI sometimes appear to be relatively insensitive to temperature changes. This may not be the case, however. There can be significant time lags before effects are noticeable. Improved understanding of linkages between biology and physics are needed.

Updates on the Pacific North Coast

The Pacific North Coast Integrated Management Area (PNCIMA) of British Columbia lies in northern Pacific Canadian waters as far south as Campbell River in the Strait of Georgia and Brooks Peninsula on the outer coast (Figure 10.)

Figure 10. The Pacific North Coast Integrated Management Area (PNCIMA), one of five large ocean management areas established for ecosystem-based management across Canada. Figure from Lucas, B.G., Verrin, S., and Brown, R. (Editors). 2007. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). Can. Tech. Rep. Fish. Aquat. Sci. 2667: xiii + 104 p.

This region holds the richest groundfish and Dungeness crab fisheries in BC, and is also a major route for cruise ships in spring and summer. Although the population density is far lower than in southern British Columbia, its residents tend to be more connected spiritually and economically to the ocean and its life.

The following summarizes some of the results included in this year's report on the PNCIMA region. Next year we hope to devote more time to this important region, and we expect our coverage to be more complete.

Temperature changes

The ocean has been cool for the past few years, and unlike in southern British Columbia where lighthouse records reveal warming in the second half of 2009, most PNCIMA lighthouse records indicate temperatures remained cool through the year (Fig. 11).

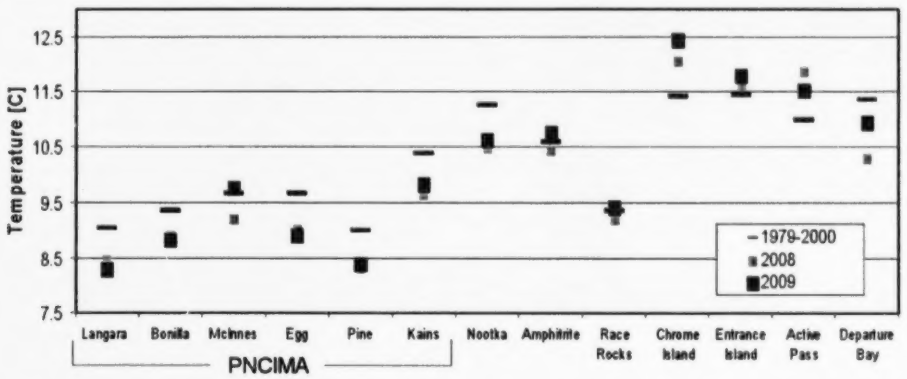


Figure 11 The mean daily sea surface temperature in 2008 and 2009 at BC lighthouse stations, and the annual mean calculated from 1979-2000 data. The first six stations (from the left) are within PNCIMA. (Contributed by Peter Chandler of DFO.)

Temperatures were below normal in all six PNCIMA lighthouse records in 2008, and in five of the six in 2009, (Fig. 11). By comparison, only two stations in BC to the south of PNCIMA were significantly below normal in 2008 and 2009: Nootka and Departure Bay.

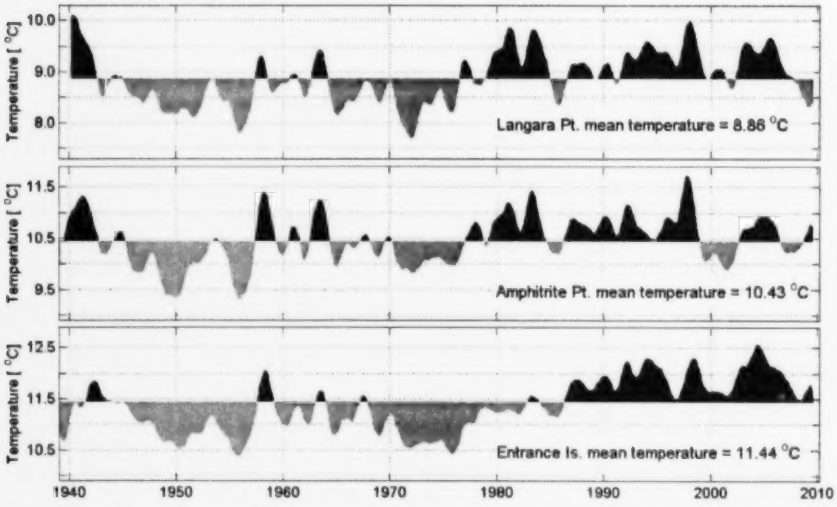


Figure 12. Temperature records at Langara Island, Amphitrite Point, and Entrance Island, where daily temperature and salinity samples are collected as part of a long-term lighthouse sampling program by DFO. (Contributed by Peter Chandler of DFO.)

This cooling in PNCIMA, in 2008 and 2009, is clearly unusual when compared to previous decades, as shown in the graph above (Fig. 12) for three lighthouse records in British Columbia. The top graph shows that the ocean waters at Langara Island, off the NW tip of the Queen Charlotte Islands, were cooler in 2008 and 2009 than observed at any time since the mid-1980s. In contrast, waters at Amphitrite Point (west coast of Vancouver Island) and Entrance Island (Strait of Georgia) began to warm in 2009; note that all three stations in Figure 12 reveal warming from the 1950s to present, a feature shared by most global temperature records.

Zooplankton

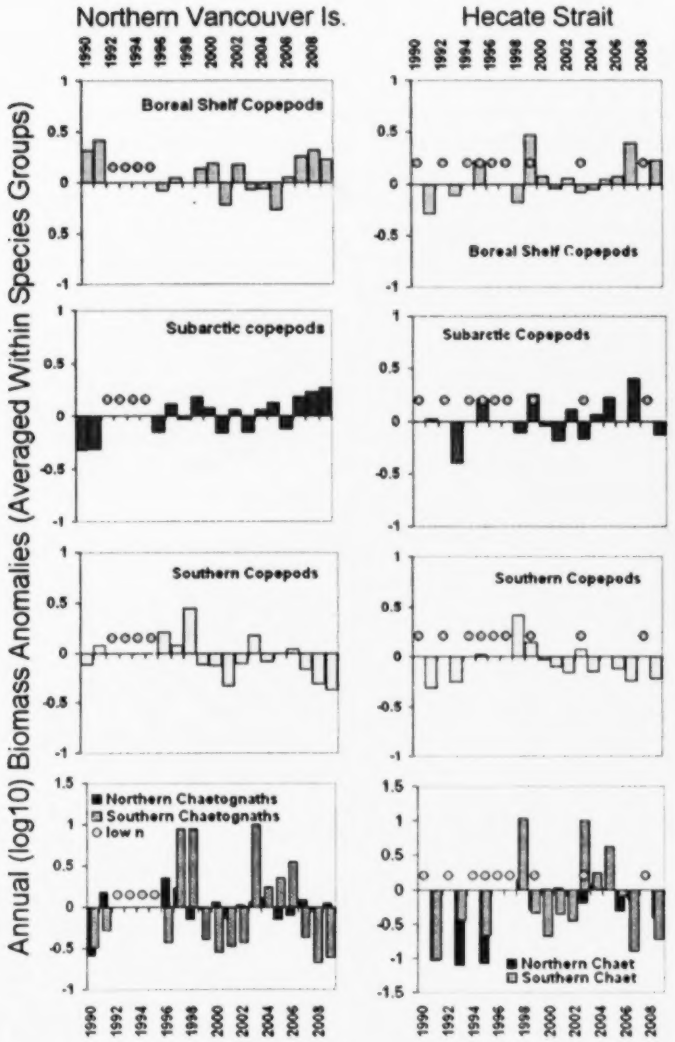


Figure 13 (below) Zooplankton time series sampling locations (red dots) off the BC continental margin. Data are averaged within major statistical areas indicated by ovals

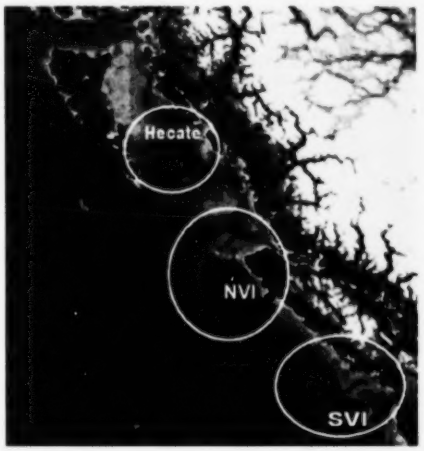


Fig. 14 (left). Zooplankton species-group anomaly time series for two regions in PNCIMA. Bar graphs are annual log scale anomalies. Circles indicate years with no or very few samples from that region. Cool years favor endemic 'northern' taxa, warm years favor colonization by 'southern' taxa. (Contributed by Dave Mackas, DFO.)

As discussed earlier, temperature largely determines the zooplankton species that dominate our coastal waters. Figure 14 reveals that cool-water, boreal shelf copepods were relatively high in biomass in 2007-2009 in northern Vancouver Island and in Hecate Strait compared to previous warm years. Subarctic copepods, another cool-water group, were dominant in 2007-2009 in northern Vancouver Island and in 2007 in Hecate Strait. No data are available for 2008 for Hecate Strait. As expected for years of cool ocean waters, a lower biomass of southern copepods occurred in 2007-2009 in both regions. Among the species of chaetognaths, it was the southern ones that declined in the cool years of 2007-2009 in northern Vancouver Island and Hecate Strait. Chaetognaths and jellyfish are the dominant carnivorous zooplankton. It is assumed that when northern, cool-water zooplankton dominate, plankton-feeding animals will benefit from this energy rich food source compared to when southern, warm-water species dominate.

Herring

Herring in the Hecate Strait area represent a combination of three major migratory stocks: the Queen Charlotte Islands stock, the Prince Rupert stock, and the Central Coast stock. Over the past decade, abundance of the Queen Charlotte Islands stock (Figure 15a) has been depressed whereas abundance of both Prince Rupert and the Central Coast stocks have remained stable (Figures 15b and c). Recruitment to the Queen Charlotte Islands stock has been depressed, with only two 'good' year-classes out of the past ten, while the Prince Rupert stock has experienced a 'good' recruitment at least every four years since 1980.

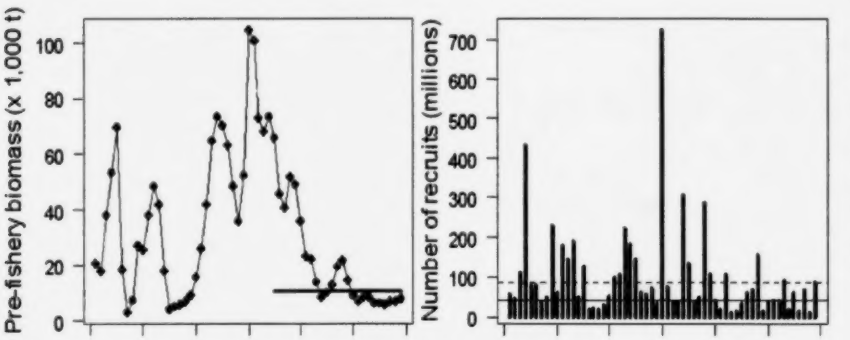


Figure 15a. Interannual variability and decadal trends in abundance (left) and recruitment (right) to the Queen Charlotte Islands herring stock. Note that 2 of the last 10 years have seen 'good' recruitment.

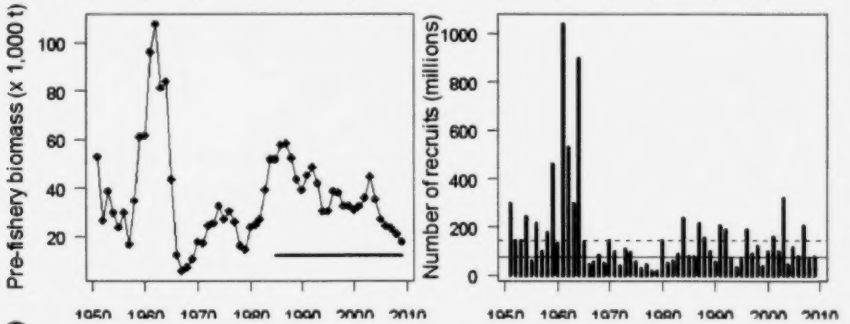


Figure 15b. Interannual variability and decadal trends in abundance (left) and recruitment (right) to the Prince Rupert District herring stock. Note that 'good' recruitments have occurred almost every four years since 1980.

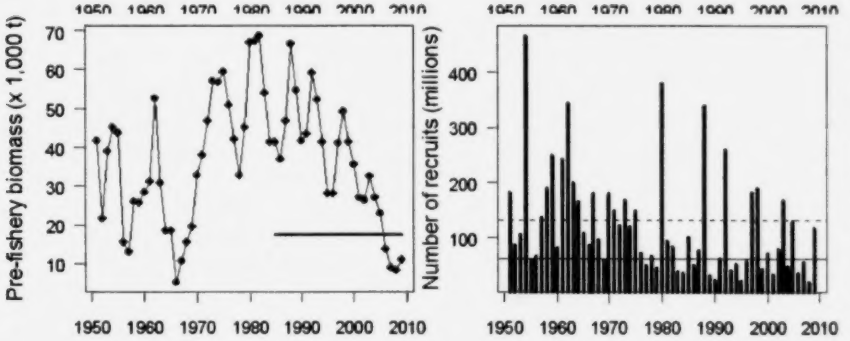


Figure 15c. Interannual variability and decadal trends in abundance (left) and recruitment (right) to the Central Coast herring stock.

In the three figures above, the solid horizontal line in the left panel denotes the commercial fishing cutoff (i.e. no fishing when estimated biomass below this level). In the right panel the boundary for 'poor' - 'average' recruitment is indicated by a solid line, and the boundary for 'average'- 'good' recruitment is indicated by a dashed line. Recruitment to the Central Coast stock (Figure 15c) has been less regular but the 'good' year-classes that have occurred were very strong.

Indications are that the most recent recruitments (2003-2005 year-classes) are 'poor' or 'average', resulting in declines all three PNCIMA herring stocks. Cool conditions in 2006

resulted in improved recruitment and slight increases in abundance in all three areas. Declining hake abundance may result in improved herring recruitment in this area in the short term.

Chinook salmon

Under the jurisdiction of the Pacific Salmon Treaty (PST), 30 Chinook salmon stock aggregates and 25 fisheries distributed between southeast Alaska and northern Oregon are managed annually to either projected landed catch targets or are limited by maximum allowed exploitation rates. Estimates of escapements or terminal runs of mature fish for each of the stock aggregates and estimates of numbers of Chinook landed or released in the PST fisheries are assembled annually and provide some of the crucial data inputs to the calibration of the Coast-wide Chinook Model (CM). The Chinook stocks (consisting of both wild- and hatchery-origin fish) and fisheries represent nearly all Chinook and fishing-related impacts known to occur within the PST jurisdiction.

Time series of abundance indices (AIs) are annually derived and reported to the Pacific Salmon Commission in technical reports prepared by the bilateral Chinook Technical Committee (e.g., TCCHINOOK 09(1), 2009 Annual Report of Catches and Escapements, TCCHINOOK 09(3), 2009 Annual Report of Exploitation Rate Analysis and Model Calibration available at http://www.psc.org/publications_tech_techcommitteereport.htm#TCCHINOOK).

The AIs are derived by dividing the annual estimated Chinook abundance, in any one fishery, by the average from the 1979-1982 'base period'. These provide a means to assess temporal and spatial trends in the relative abundance of Chinook stocks contributing to regional fisheries. Figure 16 presents time series of the three northern groups, which include two within PNCIMA (Northern BC and Central BC). Chinook appear to be rebounding from the low numbers in 2008, and predictions suggest an increase in 2010 from 2009.

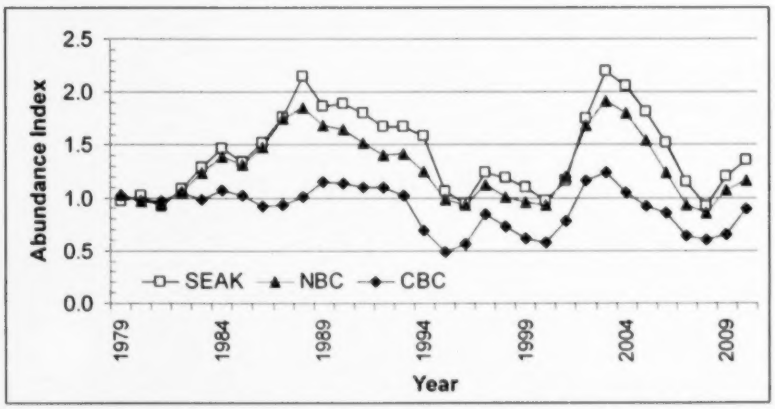


Figure 16. Time series of Chinook salmon abundance indices for three major northerly PST fisheries, 1979-2010. The fisheries are southeast Alaska troll (SEAK), northern BC troll (NBC) and central BC troll. Please note that 2010 values are forecasts resulting from the March 2010 calibration of the Coast-wide Chinook Model. (Contributed by Gayle Brown of DFO)

Phytoplankton blooms in the Strait of Georgia

We use the high spatial resolution of MERIS and MODIS satellite imagery to monitor chlorophyll concentrations along the BC coast. Availability of the higher resolution MERIS imagery (300m) has recently been improved by upgrades to Canadian satellite receiving stations.

In February and March of the years 2001-2009, MERIS and MODIS imagery showed a chlorophyll pattern recurring in three years out of nine, which suggests seeding of the early spring bloom in the Strait of Georgia from deep, glacial inlets to the north. High chlorophyll values are first observed in Jervis and Sechelt inlets in mid-February, then in Malaspina Strait, an arm of the Strait of Georgia, before spreading across the main body of the Strait in late February and early March.

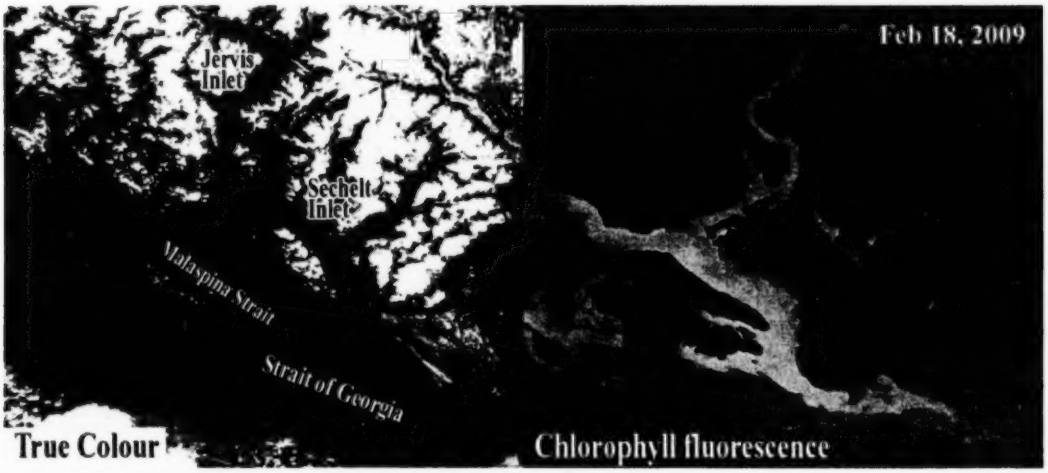


Figure 17. MERIS full resolution (300 m) images for 18 February 2009 for the central Strait of Georgia and Jervis and Sechelt Inlets to the north. The true-colour image (left) shows snow over high elevations on land, cloud cover and a digital coastline. The chlorophyll fluorescence image (right) shows ocean surface chlorophyll, here with the "Malaspina Dragon" pattern due to a bloom from Jervis Inlet entering the Strait. The name derives from its dragon-like shape, with head at lower right, tail at top left. Low chlorophyll values are shown in blue. Higher values are shown in green, yellow and orange. Land and clouds are coloured black.

We call the pattern the "Malaspina Dragon" after its shape in satellite imagery in 2005, 2008 and 2009 shortly after it entered the Strai (Fig. 17). It appears that the main spring bloom in the Strait of Georgia occurs earlier in years when the Dragon is present, suggesting that seeding from inlets in some years should be added to the list of factors controlling timing of the main spring phytoplankton bloom in the Strait of Georgia.

The first spring measurements of chlorophyll by sampling from research vessels are normally in April. Ship-based measurements reveal that chlorophyll concentrations in the Strait of Georgia in April 2009 were the highest observed in any survey since regular measurements began in 2002. Chlorophyll concentrations in April 2009 reached concentrations of >40 mg m^3 in the surface layer. In comparison, spring chlorophyll concentrations in Juan de Fuca Strait were similar to previous years (<3 mg m^3). Chlorophyll is an indicator of phytoplankton biomass, so from these measurements we can estimate the availability of plant food for the entire marine food chain. In general, nitrate concentrations are lower and phytoplankton biomass is higher in the Strait of Georgia than elsewhere in this region. Seasonally, chlorophyll concentrations in the

Strait of Georgia are highest during the spring bloom (March-April), low during the summer, increasing again at the end of the summer/early fall, and lowest during winter.

In contrast, in Juan de Fuca Strait, chlorophyll concentrations are usually lower than in the Strait of Georgia and remain generally low all year (<3 mg m^3). In summer 2009, however, upper layer (0-15 m) chlorophyll concentrations in Juan de Fuca Strait were unusually high (> 5 mg m^3) compared to previous years (2002-2008), and higher than those measured in the Strait of Georgia. At the same time, upper layer (0-15 m) nitrate concentrations in Juan de Fuca Strait and at the northern end of the Strait of Georgia were lower than those observed in June of the seven previous years.

Contaminants in Bottom Sediments

Once a contaminant has been banned on land, it can continue to cycle through the ocean and marine sediments for decades as a legacy contaminant. Polychlorinated biphenyls (PCBs), for example, were banned in stages commencing in the early 1970s, but continue to present a significant threat to marine biota, including killer whales. Lead in gasoline is another.

The concentration of PCBs in the sediment of the Strait of Georgia is decreasing with time due to reduced PCB contamination in recent sediments, but active benthic mixing keeps the surface sediment concentration high by recycling deeper, more contaminated sediments. Concentrations of lead are following a similar trend.

In contrast to PCBs, the concentration of flame retardant polybrominated diphenyl ethers (PBDEs) is increasing rapidly in sediment (Figure 18).

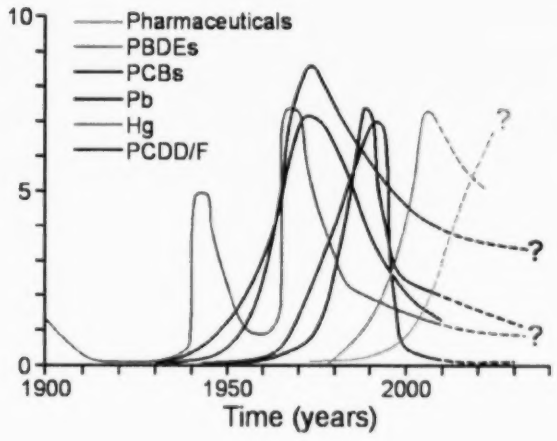


Figure 18. A conceptual presentation of contaminant loading histories to the Strait of Georgia. Pb=lead, Hg=mercury; PCDD/F =polychlorinated dibenzo dioxins/furans. The timing on the x-axis is approximately correct, but there are no units on the y-axis, because the fluxes of the various contaminants span several orders of magnitude. Contributed by S. Johannessen of DFO.

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As well, reports dating back to 1999 can be found at:
http://www.pac.dfo-mpo.gc.ca/science/psarc-ceesp/osrs/index-eng.htm

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